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TITLE: A SYSTEMS APPROACH TO DEVICE-CIRCUIT INTERACTION IN ELECTRICAL POWER PROCESSING

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Although significant work has been done on switched-mode electronic systems in the present decade, much remains to be realized. The potential of switched-mode systems is steadily increasing in step with the advancement in semiconductor device technology.

Power processing using switching techniques has very significant advantages over conventional linear techniques. Switched-mode circuits possess high efficiency, reliability and stability(thermal and otherwise) owing to the ON-OFF mode of device operation. Furthermore, some of the problems encountered in conventional (linear) operation (such as the need for providing adequate heat sinks) do not appear in switched-mode operation since device dissipation is very low. Added advantages result from the fact that in many cases more than one approach exists for the treatment of the same power processing problem, be it amplification, power conversion, or otherwise. Such flexibility allows trade-offs between various factors involved in keeping with the demands of system requirements and type of application. In this work emphasis is being placed on the development of switched-mode power conversion techniques.

We now report concisely on the work done so far and present our conclusions and recommendation for further work.

Analysis of Highly Non-linear Networks

As an aid in the synthesis of power processing systems we have been examining the general problem of analyzing highly nonlinear networks.

One approach has been to attempt to predict the qualitative behavior of a network using a relatively small amount of specific information concerning its structure. Certain analytical tools have been applied to this problem by many investigators in recent years. They enable one to isolate classes of networks in which oscillations are possible or impossible, networks which can have one or many states of equilibrium, and so forth. In [1] we summarize certain of these results.

In another, computer-based approach, we have been concerned with numerical simulation of networks in which switching-type, i.e. almost discontinuous waveforms occur. Since existing computer programs for network analysis all have certain limitations when applied to problems of this type (see, for example, [2]), we have been developing some new simulation techniques. The simulation work involves software development as well as new numerical and analytical techniques. The resulting computer programs will be used for on-line circuit analysis and synthesis. (We hope to have a time-shared remote computer terminal operating in our Systems Laboratory during 1968.)

Switched Networks and Time-Variable Systems

An important object of this investigation is to obtain a general analysis of LC networks which are switched in such a way that no energy loss occurs in the switching operation. For example, Figure 1 shows two typical sections which may be connected in series or in parallel to obtain more complex networks of the type under consideration. In Figure 1(a) the switches can be operated freely, i.e., independent of the inductor current or the capacitor voltage, while in Figure 1(b) the operating instants of the switches must be controlled and confined to instants of zero inductor current or zero capacitor voltage. A carrier modulated waveform can be used to facilitate the control of the switching instants.

The results of the general analysis will be applied primarily to the design of efficient power converters and inverters. Other possible applications to be considered are the design of general unilateral networks, and, in particular, the resonant transfer gate, as well as ac carrier control system compensation networks. A promising analytical procedure is to obtain the time-varying system function and a bi-frequency system function via state-variable analysis.

In addition to research on switched networks, some work has been pursued concerning time-variable systems considered more generally. One aspect of this work concerns modelling of large or high-order systems. A modelling technique utilizing stochastic processes has been devised [3], and further development of the technique is in progress.

High Power, High Efficiency Switched Circuits

Various pulse modulation techniques are under study for the eventual incorporation into the development of optimal power conversion circuits. This is done, with a view towards subsequent microminiaturization and integration. As part of this effort a tunable and bandwidth adjustable filter has been designed and built using integrated circuits. This work is reported in the enclosed paper which is submitted for publication in the IEEE Journal of Solid-State Circuits [4]. Further work will proceed as described in the original research proposal.

Characterization and Optimization of Power Devices

1. Power transistor and Silicon Controlled-Rectifier: A general solution of the continuity equation under the assumption of space-change neutrality is found. We are in the process of applying it to the power transistors and controlled-rectifiers.

2. Power Field-Effect Transistors (FET): Unlike the bipolar transistor, the static and dynamic transconductors of an FET decrease with increasing temperature. The power FET, therefore, should not be as prone to thermal runaway and second breakdown as is of the power transistor. Furthermore, the FET is a majority-carrier device and its operation does not depend on the lifetime of minority carriers. Its transconductance is therefore insensitive to radiation damage. Thus power FET should be more suitable for space applications.

The purpose of our work is to find out the power limitation of FET and to obtain guidelines for power FET design. It seems quite clear that the basic limitation of power FET is the channel width which limits the current flow. Shockley's theory showed that the channel width is zero at pinch-off. We have made a theoretical analysis and found a non-zero channel width at pinch-off. The region of validity of Shockley's theory is also defined. This analysis is in agreement with published experimental results. Our treatment of the problem will be published in the near future.

3. Thermally-stabilized integrated circuits: In the application of integrated circuits (IC) to power systems, a thermally-stabilized device is required as a basic building block. The diode-stabilized IC seems to meet the need well. The characterization of the device is reported in the enclosed paper which is accepted for publication in the IEEE Journal of Solid-State Circuits.[5]

References

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3. L.H. Brandenburg and H.E. Meadows, "Generation and Description of a Class of Random Processes," present at the First Asilomar Conference on Circuits and Systems, November 1-3, 1967; to appear in Proceedings of the Conference.

4. A.B. Glaser, C.C. Halkias, and H.E. Meadows, "A Tunable Bandwidth Adjustable Filter Using Integrated Circuits," submitted for publication to the IEEE Journal of Solid-State Circuits.

5. E.S. Yang, "Small-Signal Characteristics of Diode-Stabilized Linear Integrated Devices," accepted for publication in IEEE Journal of Solid-State Circuits.

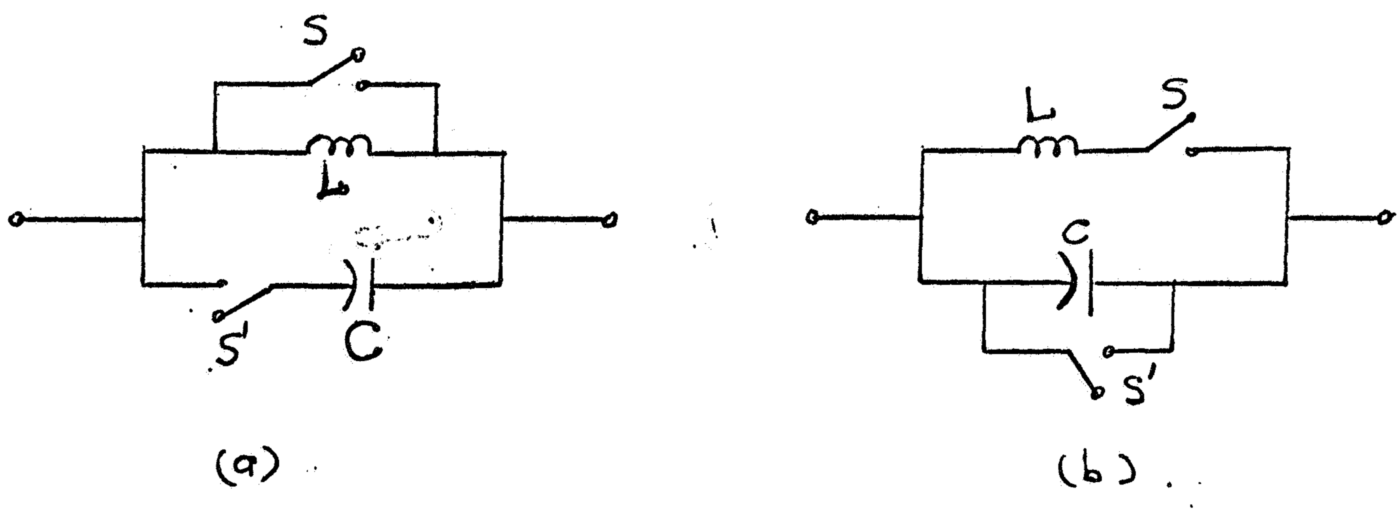

FIG. 1: Canonical Network Sections with Complementary Switches S and S'

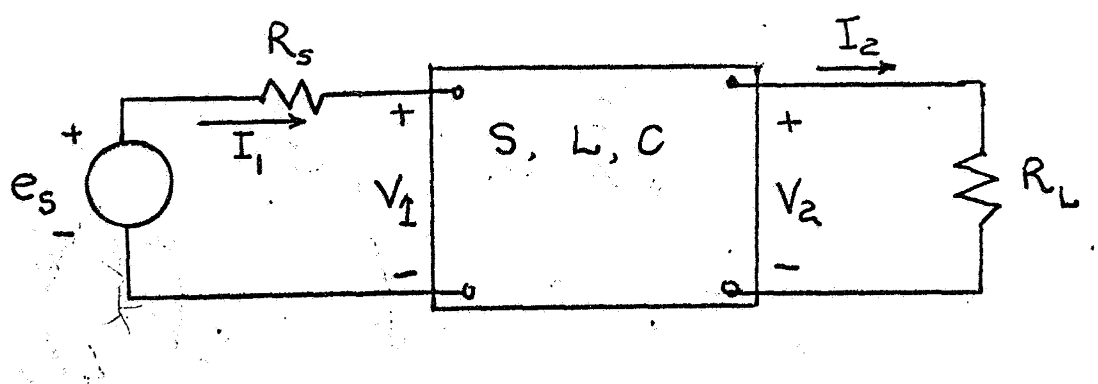

FIG. 2: Switched Lossless Network